The Quest for Quality: Optimising Platinum Casting for 21st Century Needs

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There is much interest in developing new casting alloys and techniques for platinum. Despite numerous advances in casting equipment and technology, there are still many areas to improve upon which can reduce production costs and result in a sturdier product. This review examines the casting behaviours of 900 and 950 platinum alloys with additions to increase the hardness. The main aim of this study was to discover the solidification patterns of platinum alloys from molten to the solid state, with characteristics assessed including shrinkage porosity, gas porosity and form filling. In addition, alloy hardness levels and the effects of thermal post-processing of castings were explored.

Introduction

There has always been interest in improving the casting of platinum. Following its renaissance in the early 1990s as a popular jewellery metal there have been many advances in materials and technologies that have increased the quality of cast products. Yet, despite these significant advances there remain many areas to improve upon that can greatly reduce production costs while also offering the consumer a more robust product. It is widely agreed that porosity and non-metallic inclusions are frequently found in platinum castings, and even the best-equipped casting operations have their fair share of rejections and costly rework. The reasons for this are typically attributed to platinum's high melting temperature and density, combined with a limited understanding of its solidification behaviours in the various alloyed states. With these challenges in mind, we designed a research project to better understand the casting behaviours of a number of platinum alloys that are in wide use today. Although we looked at a number of characteristics in the study, our focus was on solidification patterns of platinum alloys from molten to the solid state.

The Cost of Quality

The market price of platinum has risen from approximately $400 per troy ounce in the mid-1990s to over $1500 at the time of this writing (1). This has had an impact on the cost to manufacturers of sub-standard casting quality. If a product must be recast, the inherent metal loss in the casting process will be increased. When surface quality is characterised by metal to mould reaction and porosity is pervasive, substantially more platinum will be lost or transformed into refining dust than would be the case with a high quality casting. The high density of platinum means that even small volumes of the metal lost to inventory shrinkage in the manufacturing process have a high cost. Furthermore, platinum castings that have been welded, soldered and blended multiple times will undoubtedly suffer in terms of the quality of the finished piece.

Research Objectives

A survey of platinum jewellery manufacturers (2) was undertaken to determine what types of casting defects were encountered most frequently. The number one defect reported was subsurface microporosity emerging late in the polishing process. Unfortunately, this is the point at which manufacturers have invested the most time and money in producing a piece, and therefore are at risk of the greatest financial loss, whether in the form of rework costs or outright scrap. Other reported defects included poor reproducibility of detail, cracking, large internal voids and shrinkage porosity.

The primary goal of the present research project was to generate knowledge that might aid manufacturers who spend significantly more time finishing castings in platinum than in other precious metal alloys because they encounter excessive porosity. In addition, it was also hoped that more would be learned about which platinum alloys should perform best from a wear resistance point of view by comparing their hardness values. While this is by no means a comprehensive analysis of wear resistance, it gives an indication of the relative performance that can be expected from each alloy. Metallurgical results, including detailed microsections, are reported for 950 platinum-ruthenium, 950 platinum-cobalt, 900 platinum-iridium, and a platinum 950 alloy containing elements that substantially increase hardness (referred to as 950 PtCo+). Characteristics assessed include shrinkage and gas porosity, form filling, hardness and the effects of thermal post-processing of castings.

Solidification Characteristics

Since solidification characteristics were a key focus of the present study, a test geometry specifically designed to encourage directional solidification was used in order to attain optimal results. The graduating thicknesses, as well as the locations for the sprue/gate attachments (indicated in blue), are shown in **Figure 1**.

The casting experiments were carried out using an induction melting machine with optical temperature control. The aim was to investigate the difference in solidification patterns that occur through the use of different sprue systems, casting atmospheres and investments. A wide variety of tests were carried out, but this short report only includes results for the optimised sprue approach, non-vacuum atmosphere and a ceramic shell-type investment. Casting parameters used are listed in **Table I**. In each case two samples were prepared, using a mould temperature of 850ºC in an argon-only atmosphere and using a shell-type investment. Based on the results found, these parameters are considered sufficiently representative of the group as a whole.

Ceramic shell-type casting investments, most commonly used in industries such as medical device, aerospace and automotive are typically comprised of a series of dip and stucco layers that are proprietary to the individual foundries. A key benefit of this system over typical jewellery investments lies with its ability to be customised by the user for optimal performance rather than the 'one size fits all' approach found in standard off-the-shelf investments. Platinum's high density and melting temperature require a very high strength and high refractory investment system for success. Therefore, it is appropriate to use a customised approach that takes into account both the casting process as a whole and the specific needs of the required geometry.

Metallographic samples were prepared from each set of casting trials by sectioning the samples longitudinally,

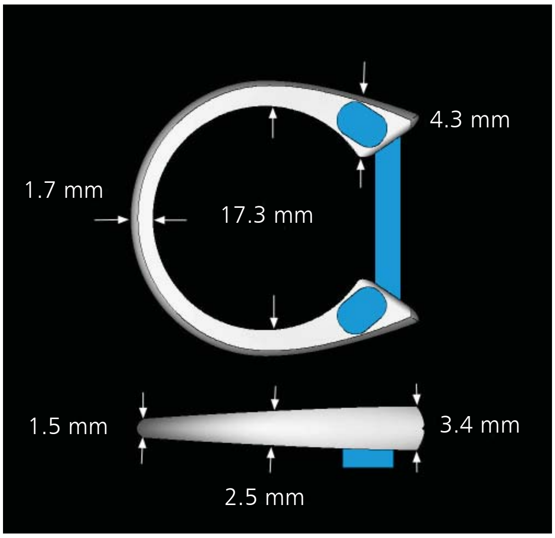

Fig. 1. Double top sprue test geometry

Table I

Parameters for Casting Trials Using Different Platinum Alloys

Alloy	Melting range, °C[a]	Pour temperature, °C
950 PtCo	1655–1680	1850
950 PtRu	1780–1795	1900
900 PtIr	1780–1790	1900
950 PtCo+	1640–1670	1830

[a] Melting range is derived from both data found in the literature and alloy supplier information. These data originate from different methods of determination and therefore are not always consistent

followed by a mount and polish. The results (shown in detail in **Figures 2–5**) suggest that shrinkage porosity was the dominant and most enduring defect present. Independently of specific casting parameters, 950 PtCo performed the best from a shrinkage porosity standpoint and 950 PtRu performed the worst. The 900 PtIr was very close to 950 PtCo, and the hard 950 PtCo+ alloy was slightly inferior to 950 PtCo with small but consistently higher levels of microporosity.

The results from an optimised double top sprue system, as shown in **Figure 2**, demonstrate that comparably thick and multiple sprues attached to heavy sections of the pattern were necessary for obtaining acceptably low levels of porosity in all platinum alloys tested. A single bottom sprue system, shown for 950 PtRu in **Figure 3**, resulted in huge voids in all alloys except the 950 PtCo, which had somewhat less porosity than the other alloys. As one

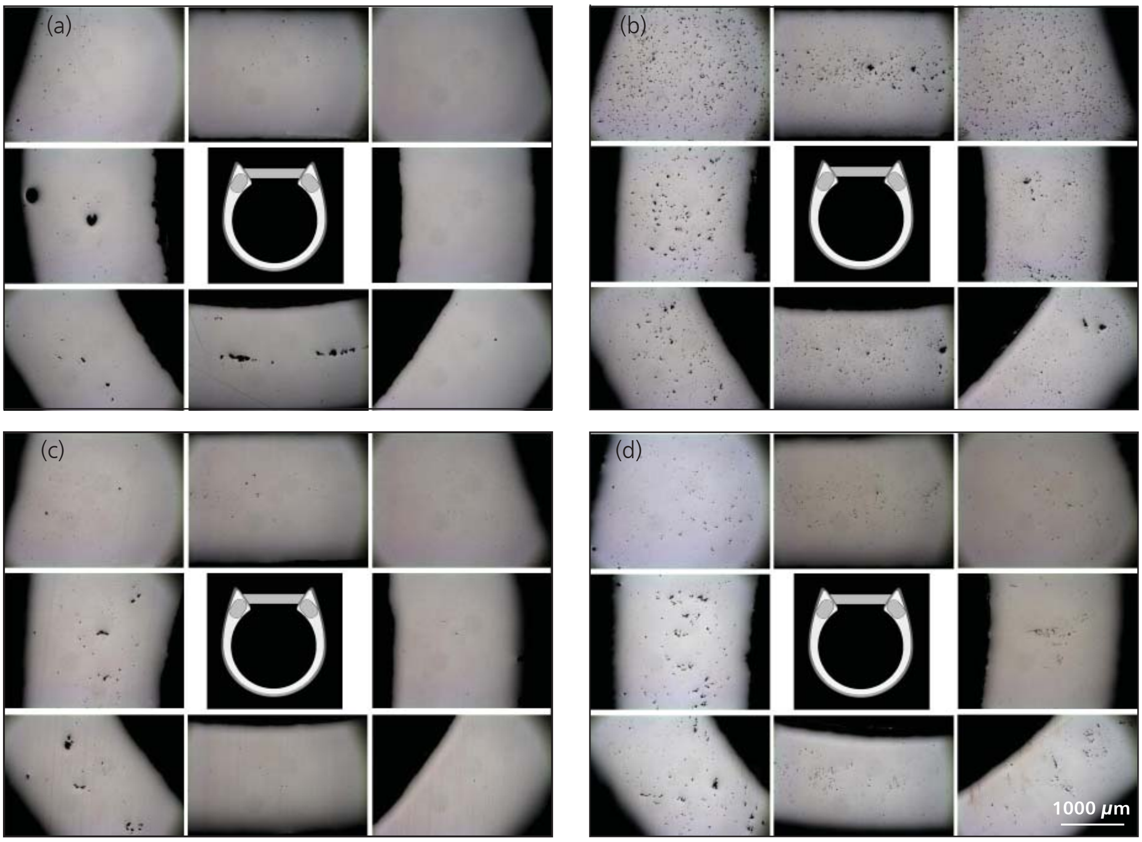

Fig. 2. (a) 950 PtCo double top sprue; (b) 950 PtRu double top sprue; (c) 900 PtIr double top sprue; and (d) 950 PtCo+ double top sprue

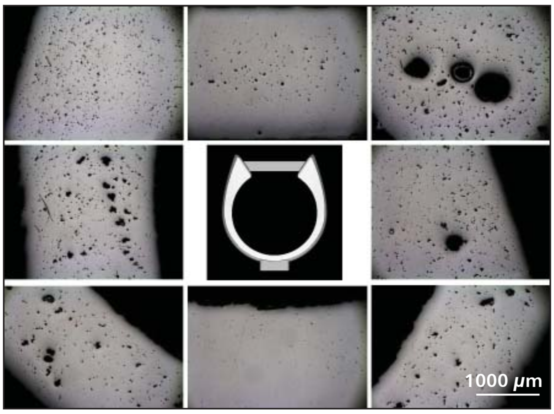

Fig. 3. 950 PtRu single bottom sprue

would expect, shrinkage and gas porosity were found to accumulate in areas that solidified last.

In sum, a significant reduction in porosity was obtained for all alloys if a well-designed sprue system was used. It is notable, however, that 950 PtRu developed a comparably large amount of scattered shrinkage porosity regardless of sprue system.

Form Filling

Fluidity of alloys is most often considered as beneficial for form filling. As can be seen in **Figure 4**, both of the cobalt-containing alloys in this study easily filled a test grid pattern at the standard pouring conditions used, while 950 PtRu and 900 PtIr failed to achieve complete fill. Cobalt as an alloying addition is well known for its enhancement of fluidity, thus this result is not too surprising. Perhaps more noteworthy is the fact that the higher fluidity of an alloy was also critical for feeding during the solidification process in order to minimise the formation of shrinkage porosity. Although this aspect has not been fully analysed, the commonly known excellent fluidity and form filling properties of 950 PtCo in comparison to 950 PtRu and other alloys suggest better feeding properties during solidification. As seen in **Figure 2**, the results for 950 PtCo lend support to this conclusion.

Hot Isostatic Pressing

Since none of the trials resulted in castings that were completely free of internal porosity, it was decided to send test samples to a thermal treatment company (3) for a densification process called hot isostatic pressing. This high-pressure thermal treatment, commonly referred to by its acronym 'HIP', is a regularly used process on base metal investment castings in quality-critical industries such as medical device and aerospace. The HIP process involves placing the castings into a high-pressure vessel for a specified period of time with inert gas applying pressure at elevated temperatures. The result is densification, which happens when the platinum's creep resistance is surpassed and plastic flow enables the surrounding material to move into subsurface voids. Time at temperature allows diffusional bonding to occur, which eliminates any internal porosity.

For this experiment the same test geometry, alloys, and casting parameters were used as shown in **Figure 1**. The entire casting tree was sent out for processing because the HIP process will only heal porosity that is not exposed in any way to the surface of the casting. Leaving the castings on the tree ensured that any porosity under the sprues would be HIPed out of the casting. The metallographic sections following the HIP cycle are shown in **Figure 5**.

Almost no porosity was left after the HIP treatment for all castings. Any microporosity was completely closed, and the few smaller cavities that were still present were probably the remainders of some larger gas pores that did not completely close during HIP.

Grain Size and Hot Isostatic Pressing

The next phase of HIP research was conducted at a later date and involved grain size analyses before and after HIP for the alloys covered in the earlier part of the study. Since the HIP process involves annealing and creep deformation at relatively high temperatures, in theory it can result in grain growth. While the initial trials did indeed show grain growth, subsequent adjustment of the HIP parameters corrected this

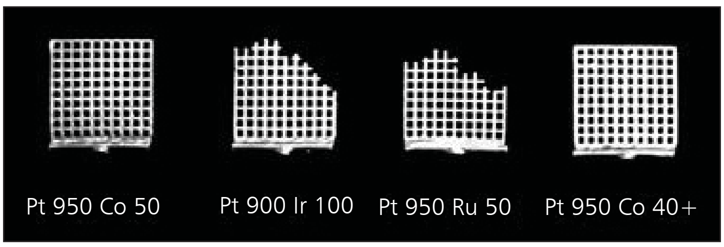

Fig. 4. Grid fill test for a selection of platinum alloys

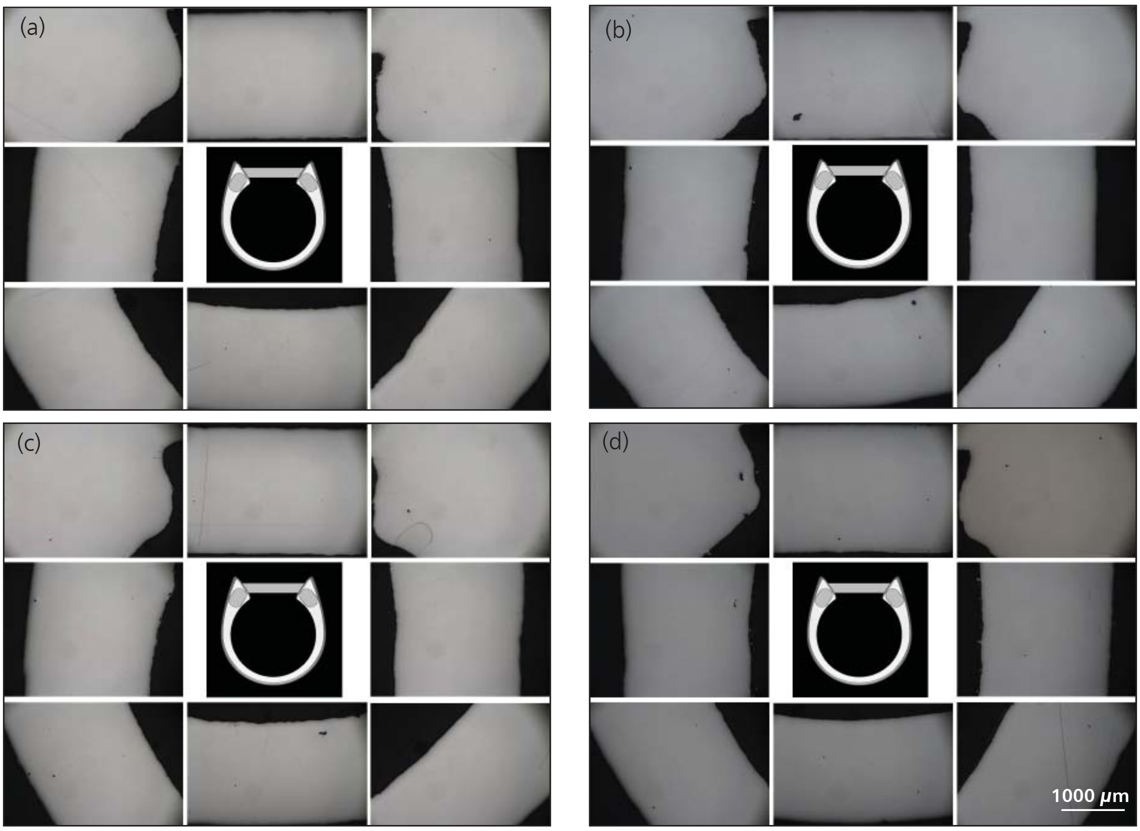

Fig. 5. (a) HIPed 95 wt% Pt-5 wt% Ru; (b) HIPed 90 wt% Pt-10 wt% Ir; (c) HIPed 95 wt% Pt-5 wt% Co+; and (d) HIPed 95 wt% Pt-5 wt% Co

condition and the same grain size could be achieved for all alloys before and after HIP. **Figure 6** illustrates this for the 950 PtRu alloy. It was further noted that the appearance of the grains had qualitatively changed after HIP despite the fact that their size had remained the same. The results of that investigation are reported in the next section on hardness.

Hardness of Platinum Alloys

While the importance of alloyed platinum hardness levels varies from industry to industry, it is of particular interest for the jewellery trade. The bulk of platinum jewellery is produced for the bridal market, thus long-term wear resistance is of prime importance. A very positive yet unexpected outcome of the HIP

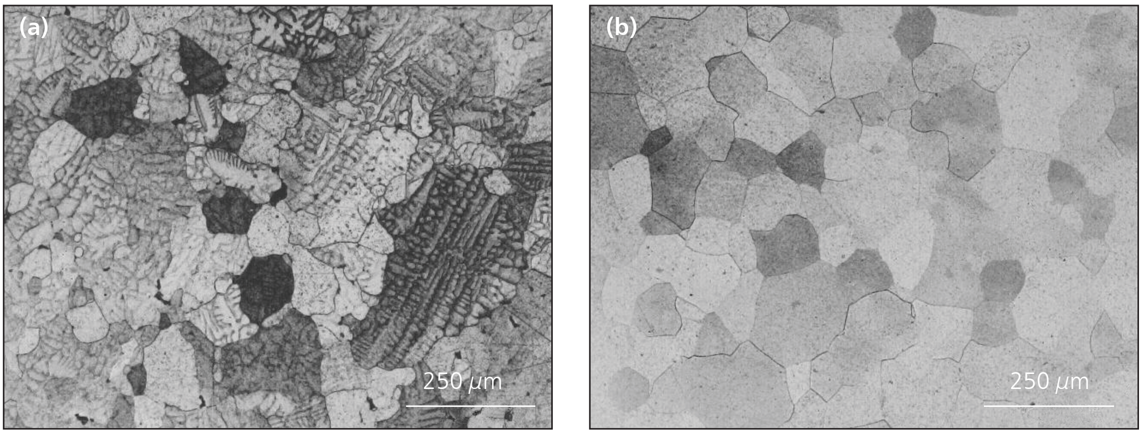

Fig. 6. (a) 950 PtRu as-cast grain structure – ASTM micro grain size 4.0; and (b) 950 PtRu post hip grain structure – ASTM micro grain size 4.0

study was an average increase in hardness of 20% for all the tested alloys. This increase in hardness might have been attributed to densification resulting from the HIP process, although the precise mechanism for this was not abundantly clear. Next, the possible role of age hardening during the slow cooling process from the HIP temperature was investigated. A second round of hardness testing was conducted on HIPed samples after an anneal cycle at 950ºC for 15 minutes, followed by open air cooling rather than slow furnace cooling. The results yielded the same hardness levels as the HIP-only condition, confirming that this was not a result of temporary age hardening, but rather an intrinsic hardness of HIPed product. In referring back to the grain size analyses in **Figure 6**, the absence of segregations in the grain interiors of the HIPed samples was noted. Hence, the qualitative difference observed was likely a result of greater homogeneity of the hardening elements, meaning these elements were more evenly dispersed throughout the crystal lattice and therefore able to harden the metal to a greater extent. This happens when alloying elements that were previously accumulating in segregations formed during solidification diffuse the platinum lattice more effectively and contribute to solid solution hardening. **Table II** shows hardness results before and after HIP for the tested alloys.

Conclusions

Platinum manufacturing operations are strongly impacted by the characteristics of the particular casting alloys that are chosen and how well the gating/sprue systems are engineered. Beginning with casting and continuing all the way through to the end use, decisions on the alloys and conditions to use have significant cost and quality implications. Solidification behaviours directly impact the labour required to finish a cast platinum item, and other characteristics such as form filling ability and hardness also impact the cost, quality and durability of the end product. It is hoped that through this research technical solutions have been demonstrated that will go some way towards improving the quality of platinum castings. Whether one finds a solution through the improved solidification of the PtCo based alloys, the use of HIP to densify and further harden shrinkage-prone alloys, or the use of intrinsically harder alloys like the PtCo+ alloy, opportunities for real and positive improvement exist.

This is an abridged and updated version of an article originally published as Reference (4).

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Table II

A Comparison of the As-Cast and HIPed Vickers Hardness Values[a] for Platinum Alloys

Alloy	As-cast $HV_{0.5}$	HIPed $HV_{0.5}$
900 PtIr	110	140
950 PtRu	130	150
950 PtCo	135	155
950 PtCo+	175	180

[a] *All data reported are mean values determined from a set of five measurements with a 0.5 kg load on metallographic cross sections*

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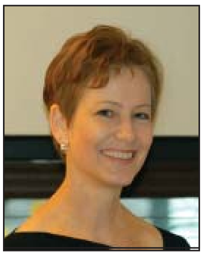

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